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TRANSACTIONS.

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No. 833.

FLUSHING IN PIPE SEWERS.

By H. N. OGDEN, JUN. AM. SOC. C. E.PRESENTED MAY 4TH, 1898.

WITH DISCUSSION.

The use of flush-tanks in connection with small pipe sewers, which has been made an integral part of the "Separate System" and generally adopted in systems caring only for house sewage, is attended with much uncertainty. In such systems it is generally specified that a flush-tank be placed at the head of every lateral, each tank being so regulated as to discharge at least once in 24 hours. The relation between the size of the sewer pipe and the amount of water used in a flush is not given, nor is the influence of grade discussed. The general law is laid down that all laterals, regardless of size, grade, or contributing population, must be supplied with flush-tanks in order to secure a self-cleansing flow in the laterals and to maintain the integrity of the system.

The financial burden of such a requirement is evident. As an example, it may be cited that in the plans for the sewerage system of Ithaca, N. Y., in which this requirement of flush-tanks was thoroughly complied with, even for the 12% grades, no less than 131 flush-tanks were required in 25.3 miles of sewers, or one for every 1 020 ft. The relative importance of the flush-tanks may also be seen by comparing

the actual cost of the sewers with the estimated cost of the tanks. The cost of the sewers, viz., the sum of the amounts of the several contracts was \$81 000, and, estimated at \$50.00 each, the flush-tanks would cost \$6 550, or more than 8% of the cost of the system. It would seem, then, that the cost of flush-tanks is by no means insignificant, but that their use increases the cost of the separate system by nearly one-tenth, besides introducing a permanent charge, both for water used and for intelligent care in maintenance. That these annual charges are no bagatelle will be apparent by again referring to the case of Ithaca. Assuming that the tanks required are of only 150 galls. capacity, a minimum amount, discharging but once a day, the water required is 19 650 galls. a day. Twenty cents per 1 000 galls. (the amount charged in Ithaca*) is a fair average amount, and at that price the daily charge for water is \$3.93 or \$1 434.45 per year. Adding to this \$600 per year as the wages of a mechanic, whose constant attention is found by experience to be necessary in examining and readjusting the tanks, the total annual charge is \$2 034.45. This, capitalized at 6%, gives \$33 908, and, added to the \$6 550, gives \$40 458 as the total expenditure on account of flush-tanks in a sewer system costing for pipe laid \$81 000. Surely the item of flush-tanks is an important one, and should be carefully examined, so that if the conditions of the sewer grade, for example, modify the necessity for tanks, or if the amount of water is a function of the time interval between flushes, or of the size of the pipe, it may be known in order that the large proportionate cost of flushing may be reduced to what has been found by careful investigation to be an absolute minimum.

That the requirement given above is felt by present-day engineers to be largely in excess of necessity is sufficiently evident from a study of the paper by F. S. Odell, M. Am. Soc. C. E., entitled "The Separate Sewer System Without Automatic Flush-Tanks,"† and the subsequent discussion, in which the author says that at Mt. Vernon, N. Y., no flush-tanks are used, and that, while hand-flushing by means of fire hose is practiced at intervals of six months, even this infrequent flushing does not appear necessary, as examination of the sewers invariably shows a very wholesome and satisfactory condition. In the discussion very little positive evidence is given, but the experiences recorded go chiefly to show that while automatic flush-tanks do not in them-

* *Manual of American Water Works*, 1897.

† *Transactions*, Vol. xxxiv, page 223.

selves make the separate system practicable, there is, nevertheless, a need, under certain conditions, for flushing, those conditions being as yet not fully determined.

The questions, answers to which are essential for an intelligent disposal of flush-tanks on a sewer system, are four, viz.:

1. What is the relation, if any, between the grade of the sewer and the necessity for automatic flush-tanks?
2. Assuming a need for automatic tanks, how does the grade of the sewer affect the amount of water required, and what is the proper amount to be used?
3. How often should tanks be discharged?
4. What effect does the substitution of a 6-in. for an 8-in. lateral have on the necessity for tanks and on the amount of water to be used?

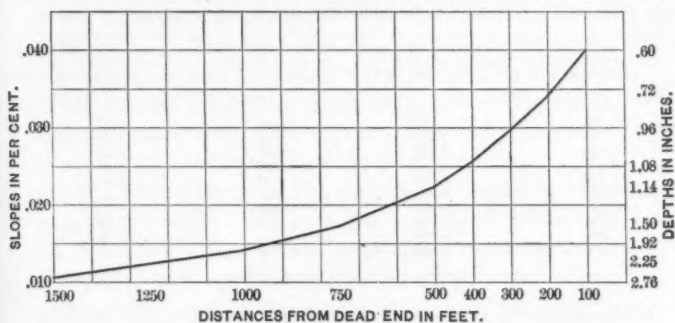


FIG. 1.

Before attempting to answer these questions, it will be well to look at the subject broadly, and consider the hydraulic problem involved. Sewage is water carrying in suspension less than 1 part in 1 000 of solid matter, and sewers are supposed to be so laid that the resulting velocity of flow is sufficient to keep this solid matter in suspension. This suspending and scouring power probably depends on the velocity, and on the depth, of the sewage stream, and if either gets below a certain point, sedimentation will follow and a deposit take place. It is generally stated that a velocity of about $2\frac{1}{2}$ ft. per second is required; but the effect of depth is neglected. At the lower end of a 6-in. lateral the depth and velocity are assumed to be sufficient to prevent this sedimentation, but as the contributing population grows less toward the upper end, the depth and velocity decrease and

the transporting power of the stream falls so low as to allow the solid matter, brought into the sewer by the house drains, to become stranded. This deposit increases by gradual accumulation until the sewer is blocked, until the head from the backed-up sewage is sufficient to carry away the obstruction, or until the discharge of the flush tank (and here is seen its true function) takes up the obstruction and carries it to a point where the depth and velocity of the sewage will hold it in suspension. Table No. 1, and the diagram Fig. 1, are given to show the requirements in grade to maintain a velocity of $2\frac{1}{2}$ ft. per second in a 6-in. lateral, assuming a constant contributing population of 76 persons per 100 ft. of sewer, with a daily flow of 60 galls. per capita, and with the assumption of one-half flowing off in 6 hours.

TABLE No. 1.

Distance from dead end in feet.	Discharge in cu. ft. per sec.	Slope in ft. per foot.	Depth of flow in inches.
1 750	0.245	0.0103	3.00
1 500	0.210	0.0104	2.76
1 250	0.175	0.0123	2.25
1 000	0.140	0.0140	1.92
750	0.105	0.0174	1.50
500	0.070	0.0225	1.14
400	0.056	0.0256	1.08
300	0.042	0.0302	0.96
200	0.028	0.0342	0.72
100	0.014	0.0400	0.60

The diagram (Fig. 1) shows that, taking n equal to 0.013, and computing velocities by Kutter's formula, a grade of 1% is required for a 6-in. pipe half full for a velocity of 2.5 ft. per second, and that if the amount of flow constantly decreases, the depth of flow decreases also, and the grade, in order to maintain the same velocity, must be increased according to the diagram. The diagram is given for two reasons; first, to show that by the accepted laws governing the transportation of material in flowing water, lateral sewers could be laid, theoretically, on such grades that no flushing would be necessary, since, with grades which continually increase toward the upper end, the corresponding velocities would always be equal to that required to transport matter in suspension; second, that as the grade of the sewer increases, the distance from the upper end to the point where the stream reaches the velocity required to carry matter in suspension decreases, and so the aid required from flush-tanks is less. No value can be

placed on the grades given, as the diagram is based on the assumption of a house with five persons every 66 ft., and this is not always the case, but it is believed that there is a grade at or beyond which flush-tanks are not required, and that if the distance to which the flushing power extends is a function of the amount of water discharged, then this amount should be less on the steeper grades.

Referring again to Mr. Odell's paper, it is first noted that at Mt. Vernon, with grades of from 0.5% to 6% no flush-tanks are used, and a good hand-flushing twice a year answers every purpose.

In the discussion, Mr. Hering says that on light grades flushes of 200 to 300 galls. generally lose their flushing power after passing a few hundred feet through the pipe, and that sometimes after 500 ft. he had been unable to detect any difference in the flow due to the tank.

Mr. Kiersted writes that in one system designed by him he recommended flush-tanks only on laterals of less than 0.5% grade, and for five years the system has been in operation with but few stoppages.

Mr. Folwell writes that in his experience he has omitted flush-tanks on grades from 6% to 12%, and on the 6% grades no stoppages were discovered, nor were there any odors.

Mr. Le Conte intimates that flush-tanks as built do not answer their purpose, for where grades are light and the flush most needed, they do the poorest work; and the large quantity of water needed, to be effective, must be obtained by some other means.

Mr. Odell maintains that flushes of 200 galls. or less fail to flush a sewer properly, especially on flat grades where flushing is most needed.

A table by Mr. Allen shows that on grades greater than 0.5% a velocity of more than $2\frac{1}{2}$ ft. per second is maintained over 1 000 ft. from the flush-tank, but on lesser grades the velocity drops to 2 ft. or less within 600 ft.

In order to obtain an insight into general engineering feeling in the matter, and, at the same time, reap the benefit of any experience which was to be had, the author sent out on January 17th, 1898, 150 reply postals, reading as follows:

" ITHACA, N. Y., January 17th, 1898.

" DEAR SIR:

" To aid me in deciding as to the necessity for flush-tanks for our sewer system, will you kindly answer the following:

" I.—Do you find flush-tanks a necessity, or is periodic hand flushing sufficient to keep sewers clean ?

" II.—Does the element of grade affect the question, and within what limits of grade are tanks required ?

" III.—Does your experience show any relation between the minimum amount of water required for effective flushing and the grade of the sewer ?

" Thanking you in advance for your kind assistance in this matter,

" I am, yours very truly,

" H. N. OGDEN,

" *Engineer, Ithaca Sewer Commission.*"

These postals were sent to those cities of between 10 000 and 60 000 population, in the New England and Middle Atlantic States especially, which were reported in *The Manual of American Water Works for 1897* as having separate or sanitary sewers. Eighty answers were received, and the courtesy and good-will expressed in all was unmistakable and much appreciated. The same story was told by them in nearly all cases. " I would be pleased to answer your questions fully, but this is the best that I can do for you," or " This is only my idea, while I can readily understand that what you want is the result of actual experience," or " I cannot give you the desired information, but would be thankful to you if you would let me know the result of your inquiry." The results given below in a brief summary chiefly show how uncertain and vague is the knowledge on the subject, and how necessary some experiments and investigations.

In answer to question No. 1, whether flush-tanks were necessary, of the eighty replies seventeen had no opinion on the subject, and twelve had experience only with combined systems, but had, according to their replies, found no trouble in keeping the ends of their 10-in. and 12-in. laterals clean with rain or with hand-flushing. Twenty-six of the eighty used periodic hand-flushing and found it to answer every purpose, keeping the sewers clean and free from obstructions. Twenty-five either used flush-tanks or considered them a necessity for small pipe sewers. It was not possible in these last answers to separate actual experience from personal conjecture on the question, so that this number may include many hearsay opinions.

The evidence is not very clear. The fact that twenty-six used hand-flushing satisfactorily indicates that such flushing is sufficient. That it must be properly and regularly done, however, is made plain

by the fact that, out of the twenty-five believing in flush-tanks, nine had tried periodic hand-flushing, found it uncertain and irregular, and had put in flush-tanks, to secure proper attention. On the other hand, of the twenty-six believing in hand-flushing, two came to that opinion after becoming disgusted with the uncertainty of tanks.

To the second question, only twenty-three of the eighty ventured an opinion. Of these, eight thought that the grade did not affect the question, but that flush-tanks were as necessary on steep as on flat grades. One engineer explained his position by saying that while the velocity on the steep grades might be greater, yet as the depth would be less, the transporting power would be less, and therefore tanks were equally necessary. Of the fifteen who thought that tanks are not needed above a certain grade, six merely ventured it as an opinion, and nine fixed the limit at from 0.5% to 3 per cent. Four give 1% as the limit; one, 3%, and the other four give less than 1 per cent.

Only six replies were given to the last question, whether the amount of water in the flush-tank should be varied with the grade of the sewer. Of these, two thought that no difference should be made; three thought that less water could be used on the steeper grades, but had no definite opinion as to the relative amounts; while one well-known engineer, who has thoroughly studied the workings of the sewer system under his care, writes that he finds one flush daily on a 2% grade as effective as two flushes daily on a 0.5% grade, each flush of 300 galls.

The general conclusion from the replies is that occasional flushing on low grades, probably below 1%, is needed at the upper ends of laterals; that this may be accomplished, either by hand-flushing or by the use of automatic tanks; that if tanks are used, less care and vigilance are required in inspection and oversight, but if they are used, the periodic examination of the system, which should not be omitted, is apt to be irregular, and if a tank fails to work or if an obstruction occurs below the effect of the flush, a serious nuisance may result; that if hand-flushing is used, a constant and regular inspection must be practiced, although actual flushing may be required only once a month or less. The amount of water needed in flush-tanks is not known, nor the relation between amount and grade.

With a view of obtaining more information on this apparently unstudied subject, the author carried on some experiments in the spring

of 1897. He was assisted by Mr. I. W. McConnell, C. E., who had been the writer's valued assistant on the construction of the Ithaca sewer system for two summer vacations. The results of the experiments have been recorded by Mr. McConnell in a thesis for the degree of Civil Engineer in Cornell University.

The sewers on which the experiments were made, and which were chosen so as to afford a variety of grade, with as long lines as possible, were all 8-in. pipe, and each had at the upper end a manhole about 4 ft. in diameter at the bottom. Flush-tanks of usual commercial size discharge at a rate of about 1 cu. ft. per second, and, by repeated experiment, the opening from the manhole into the sewer was reduced to such a size (about 5 ins.) that the rate of discharge varied from 0.89 cu. ft. per second for 4 ft. head in the manhole to 1.1 cu. ft.

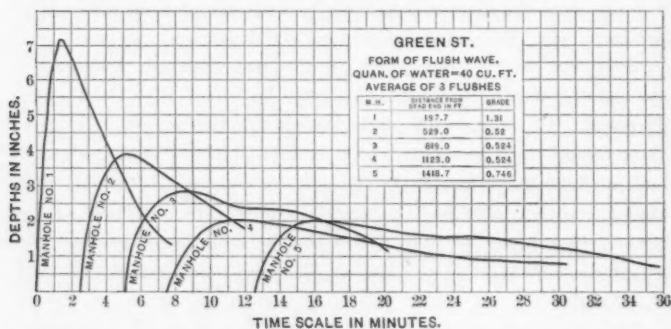


FIG. 2.

per second for 6 ft. head. These conditions it was thought approximated closely enough to the workings of a flush-tank. A 5-in. opening was cut in a pine board firmly held against the end of the 8-in. pipe; then a flat cover, 6 ins. in diameter and faced with rubber, was provided, which, placed over the opening and held there by a light stick braced against the back of the manhole, made an effective plug. The manhole was filled to any desired depth by means of fire-hose attached to neighboring hydrants, and then, by means of a cord fastened to the stick and to the cover, the contents of the manhole were discharged into the sewer. The capacity of the manholes at depths varying by 6 ins. was determined by measurement, so that by filling to the proper depth any desired amount of water could be discharged. The effect of the flush waves was then noted at the

successive manholes down the line. No determinations of the velocity of the wave were made, the effect being judged by the depth of the wave, and by the force shown in moving gravel, etc., placed in the different manholes. The wave depths were read by different observers stationed in the manholes, where they recorded as rapidly as possible (usually every seven seconds) the depth as marked on a thin vertical scale placed in the sewer. Figs. 2 to 5 show the wave forms and the progressive flattening as the wave gets farther and farther from the flush-tank.

To test the transporting power of the wave small brickbats and gravel of various sizes, coated with paint so as to be recognizable, were placed in the invert at the manholes. A considerable growth of what was apparently of vegetable origin had become attached to the sides and bottom of the pipe, and the value of the flush in removing this growth was also noted. The order of procedure was to examine and note the condition of the line, and, after placing the gravel, etc., to make a number of flushes, each of 20 cu. ft., and note the results. Then, increasing the amount discharged to 30, 40, 50 and 60 cu. ft., the respective results were noted. Then, either the whole pipe was scraped by a rubber-edged piston-like cleaner, or merely the manhole inverts and about 6 ft. each way into the pipe, and the flushing repeated. The following tables give the results on the different lines:

TABLE No. 2.—GREEN STREET SEWER.

Volume of flush.	EFFECTS AT				No. of flushes.
	Manhole No. 1.	Manhole No. 2.	Manhole No. 3.	Manhole No. 4.	
25 cu. ft. . .	Scoured clean.	Scoured clean.	No effect.	No effect.	1
30 " " " "	"	"	"	"	1
40 " " " "	"	"	{ Several stones started. }	"	8
60 " " " "	"	"	{ Small gravel generally started. }	"	2
80 " " " "	"	"	"	"	2
120 " " " "	"	"	"	"	3

Before commencing the work, the examination of the pipe showed it to be practically clean, with no ground-water, except between the third and fourth manholes, where there was a stream perhaps $\frac{1}{4}$ in. deep. There were no house connections, but there was a small depth

of silt, and small pieces of cement left from construction, also a slight growth on the sides and bottom of the pipe. Gravel of all sizes placed in the pipe at the flush-tank was carried through to manhole No. 1 in two flushes of 25 cu. ft. each, the first flush alone not being sufficient. The gravel scoured out of the bottom of No. 1 manhole by the first flush was not brought to No. 2 until the 80-cu.-ft.

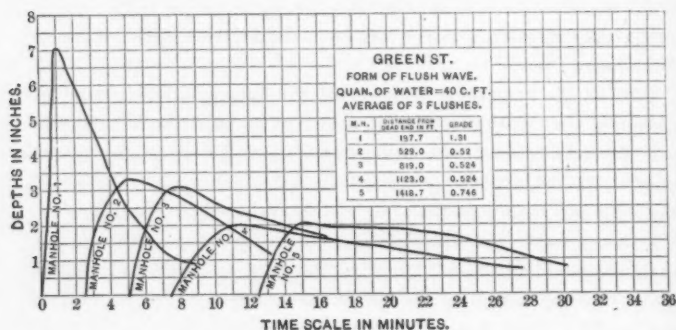


FIG. 3.

flush was put in, and no gravel scoured out of No. 2 was brought to No. 3 by any of the flushes. After the seventeenth flush as above, the pipe was thoroughly scraped and cleaned, and flushes eighteen to twenty-eight made. Similar results were obtained, except that the flushes carried the gravel about 200 ft. farther than before and seemed effective for that distance.

TABLE NO. 3.—CAYUGA STREET SEWER.

Volume of flush.	Manhole No. 1.	Manhole No. 2.	Manhole No. 3.	Manhole No. 4.	No. of flushes.
30 cu. ft. ...	Scoured clean.	No effect.	No effect.	No effect.	3
40 " ...	"	{ Disturbed but not cleaned. }	"	"	7
60 " ...	"	Partly scoured.	{ Some vegetable growth passed through. }	"	2
80 " ...	"	Cleaned.	"	"	3

In Cayuga Street there were a few connections and little flow, so that the condition of the pipe was very foul; there was also a heavy vegetable growth in the pipes.

On Linn Street no comparative records could be made. The pipe was clean from the flush-tank to Manhole No. 1, and in this length there were no connections. From No. 1 to No. 2 it was slightly foul, and very foul the remainder of the length. There were two house connections on the line. Five flushes of 20 to 60 cu. ft. were made.

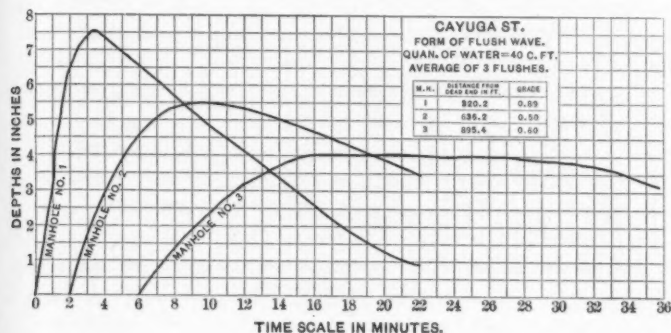


FIG. 4.

Each was very effective, one apparently as much so as another. All obstructions introduced were removed at once from manholes Nos. 1 and 2. A steady flow 1 in. deep from the hose carried everything forward at once to a point beyond No. 2 and to the flatter grade.

TABLE No. 4.—AURORA STREET SEWER.

Volume of flush.	Manhole No. 1.	Manhole No. 2.	Manhole No. 3.	Manhole No. 4.	No. of Flushes.
40 cu. ft....	Cleaned.	Cleaned.	No effect.	No effect.	3
60 "	"	"	Disturbed.	{ Water dirty; some vegetable growth came through.... A few stones disturbed.	7
80 "	"	"	"		2

TABLE No. 5.—FIRST STREET SEWER.

Volume of flush.	Manhole No. 1.	Manhole No. 2.	Manhole No. 3.	Manhole No. 4.	No. of Flushes.
40 cu. ft....	Cleaned.	No effect.	No effect.	No effect.	5
60 "	"	"	"	"	3
80 "	"	"	"	"	2

On the Aurora Street line, the pipe was very foul, chiefly from a hospital connection at the upper end. The vegetable growth was large, and the accumulations of organic matter very evident.

On Buffalo Street, where the grade is about 12%, the effect of the flush was amazing. Where any sewage at all flows in the pipe, it is

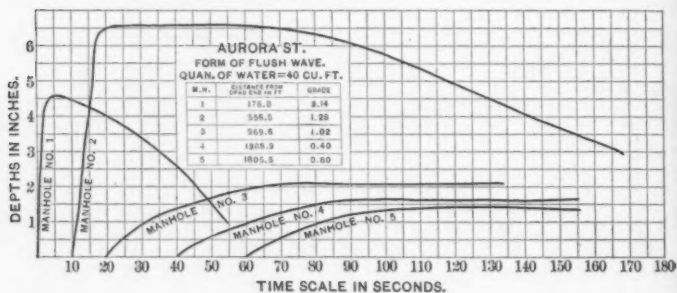


FIG. 5.

sufficient to remove all obstructions. A flush of any volume rushes down the hill at a high velocity, with piston-like action, and sweeps everything before it.

Table No. 6 gives the distances and grades between manholes on the lines used in the experiments.

TABLE NO. 6.—DISTANCES AND SLOPES BETWEEN MANHOLES.

Description.	GREEN ST.		CAYUGA ST.		AURORA ST.		FIRST ST.		LENN ST.	
	Distance in feet.	Grade percentage.	Distance in feet.	Grade percentage.	Distance in feet.	Grade percentage.	Distance in feet.	Grade percentage.	Distance in feet.	Grade percentage.
Dead end to Manhole No. 1.....	298	1.31	320	0.89	177	3.14	371	1.00	331	2.94
Manhole No. 1 to Manhole No. 2.....	231	0.52	316	0.50	390	1.28	341	0.50	278	2.70
Manhole No. 2 to Manhole No. 3.....	290	0.52	250	0.60	413	1.02	394	0.57	317	0.50
Manhole No. 3 to Manhole No. 4.....	305	0.52	.....	.....	419	0.40	393	1.00	.....	.....
Manhole No. 4 to Manhole No. 5.....	296	0.75	.....	.....	417	0.60	.....	.....	.....	.....

The manager of the Van Vranken Flush-Tank Company gives his practice in proportioning the sizes of flush-tanks for any particular

sewer, as follows: The capacity of the reservoir should be equal to one-half that of a length of sewer in which the grade produces a rise equal to the diameter of the pipe; so that the Green Street line, 8 ins. diameter, and 0.5% grade, should have a discharge of half the volume of the pipe, $\frac{1}{2} \times 100$ in length, or 23 cu. ft.; and for a 1% grade one-half of that, or 11.5 cu. ft. He says further, and the statement has been confirmed by the author's work, that an 8-in. pipe on a 0.4% grade will flow about one-third full at a distance of 300 to 400 ft. from the tank discharging the above amount; and that on a 5% grade the water will come down as a solid piston for any discharge greater than 14 cu. ft.

The manager of the Pacific Flush-Tank Company writes that as a rule he does not interfere with engineers in their design for tanks, but, in his opinion, a flush of 175 galls. on a 1% grade is sufficient, and on any flatter grade twice that amount of water should be used, or, in other words, as he says, "long lines or flat grades require greater capacity of tanks than steep grades or short lines."

Conclusions.—The following conclusions are based upon data on this subject published previously; upon the experience of engineers in different parts of the country; upon the flushing diagrams published recently by J. W. Adams, and upon observation and the special experiments made in Ithaca; and it is believed that they are justifiable and are a safe guide as to the use of flush-tanks.

(1) Flushing of some sort is required at the upper ends of laterals, the frequency and amount depending on the number of house connections, on the carefulness or prodigality in the use of water by the householder, on the grade and size of the sewer, on the character of its construction, and on a mysterious something which defies definition, but which produces frequent accumulations in one line and does not affect another, apparently like the first.

(2) This variety in the conditions prevents any exact statement of a relation between the quantity of water which should be discharged from a flush-tank and the grade of a sewer, but it plainly indicates that the advantage of automatic flush-tanks lies in a general guarantee or insurance against accumulations in the upper part of the laterals, while periodic hand-flushing must be depended on only when in charge of a responsible, indefatigable and intelligent caretaker.

(3) Judging by the experience at Ithaca, and despite the statements of other engineers, it seems to the author that on grades of less than 1%

automatic flush-tanks are an economic necessity, even where water has to be paid for, the added expense of frequent hand-flushing more than off-setting the possible discharge of flush-tanks when not absolutely necessary.

(4) The volume of water discharged should not be less than 40 cu. ft., and the effect of the flush can hardly be expected to reach more than 600 or 800 ft. Below this point accumulations may occur which must be removed by hand-flushing and carried on to a point where the sewage flow has the necessary transporting power.

(5) On flat lines and where obstructions occur below the influence of the flush-tank, a second flush-tank, placed about 80 ft. from the first, will be more effective than increasing the first tank to a capacity of three times its original discharge.

(6) The frequency of discharge should depend on the local conditions, but it is probable that the maximum interval depends on the practical working of the siphon, so that the usual prescription of once in twenty-four hours is a safe rule.

(7) If tanks are used on grades greater than 1%, 15 to 20 cu. ft. give as good results as larger amounts, with the same rule as to frequency of discharge.

(8) However, economy is best served, on grades above 1%, by omitting flush-tanks, and resorting to periodic hand-flushing at such intervals as experience shows to be necessary on the different lines. In most cases semi-annual or quarterly flushings, with a hose, are sufficient.

(9) On grades greater than 3% flush-tanks are unnecessary, and their installation is a waste of money.

(10) Hand-flushing should be performed and tanks discharged at night, as a flow of even an inch in a sewer offers a large resistance to the flushing action; while, with a pipe flowing half full, the effect of a flush-tank is scarcely visible.

DISCUSSION.

RUDOLPH HERING, M. Am. Soc. C. E.—Words of encouragement Mr. Hering should be given to every one who finds and utilizes an opportunity to undertake experiments on this subject, as there is but little useful information concerning it in existence.

The experiments described in the paper are valuable, so far as they go, and furnish data from which a better judgment, than was possible before, can be obtained on a number of points. The author confines his recorded experiments to 8-in. pipes, and to the same quantity of flushing water in each case, varying only the gradients of the pipes.

The answers received in response to the postal card inquiry indicate first, that "occasional flushing on low grades, probably below 1%, is needed at the upper ends of lateral sewers," and, secondly, that automatic flushing requires less labor and less vigilance than hand-flushing, though, without proper inspection, the former allows, as he says, "a serious nuisance to result." The speaker thinks that the automatic flush-tank should not in any measure be made responsible for "the serious nuisance," but that the responsibility, in such cases, is entirely due to the failure of sufficient or efficient inspection, a *sine qua non* for every sewerage system that is to be kept in order, whether automatic flush-tanks are used or not.

The author did not make his experiments with automatic tanks, but by filling a manhole with an amount of water and drawing a plug, by which the water escaped into the 8-in. sewer, through an opening 5 ins. in diameter cut in a pine board. This circumstance should be emphasized a little, so that the results may not be quoted as applying to automatic tanks. In the latter the rates of discharge and the velocity of the water issuing from the tank will differ, although not materially, from those of the former case.

It is also advisable, in such experiments, to have the velocity of the water measured at different parts of the wave, instead of calculated from the gradient or judged by the force of moving gravel, etc. It is to be hoped that such velocity measurements may be made at an early day, as a formula gives but a rough approximation to the velocity. In the same pipe with the same section and slope of the water, the velocity will be different when the water is rising from that which obtains when the water is falling. The usual slope formulas take no account of this fact. It has been reported that the stream flows quicker just after the crest of the wave has passed a manhole than before it arrives at this place. Further, the loss of head in the cleaning process, by loosening and carrying along deposit and sticky material would also be properly accounted for by actual velocity measurements, if such were made.

Mr. Hering. The European experience with flushing sewers dates back almost fifty years. In the speaker's report on this subject in 1880,* the results of such experience are given. There has been almost no progress made since then in the methods used, but, fortunately, flushing has become more common. It was almost nowhere practiced in America before 1880.

The principle that "long lines of flat grades require greater quantities than short lines of steep grades" was then well recognized in Europe. Small tanks were used only at the heads of short or steep sewers, where flushing requires but a small quantity of water. For flushing large sewers on flat slopes, the sewage itself was stored for this purpose in large quantities, or ground-water was collected in large cisterns, because in these cases a large quantity of flushing water is required. It had also been stated in Europe that daily flushing with automatic tanks was not everywhere considered necessary. It was the practice then, as it is now, to flush the smaller sewers by hand at intervals varying from twice a week to twice a month.

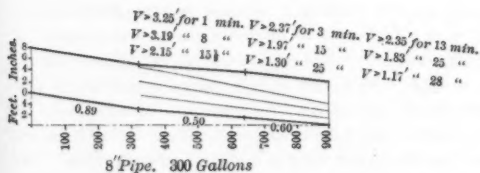
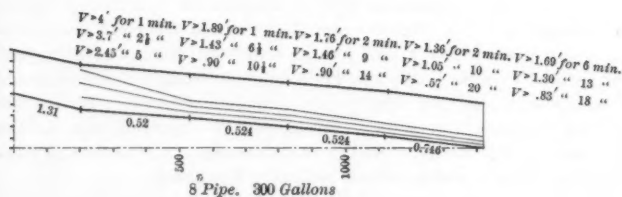
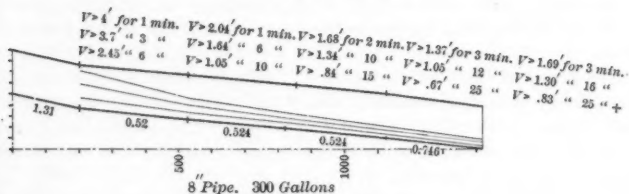
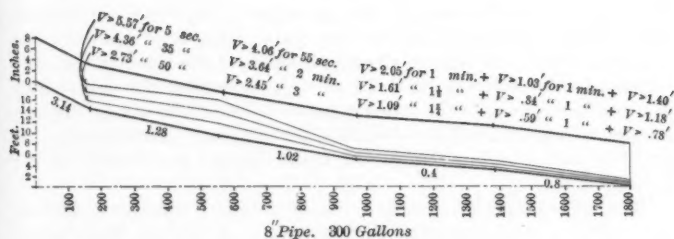
The assertion made by the author that automatic flush-tanks cause an additional expense of more than 8% of the cost of the system is hardly fair. He estimates \$50 as the cost of such a tank, but apparently overlooks the necessity for having a manhole at the head of the sewer in any event, and he should charge the flush-tank only with the necessary appliances for flushing, or \$15 to \$20 instead of \$50.

He also charges the flush-tanks with the annual expense for water and more intelligent maintenance. No doubt 20 cents per thousand gallons may be chargeable in some cities, and where private companies have a franchise granted on liberal terms; but the average cost of water in American cities is by no means so great. Its average value is much less, and in many cases is less than half of that figure.

The author's deduction that the cost chargeable to flushing sewers amounts to about one-half of the construction account is, therefore, wide from the true mark, if it were generally applied. In the case of Ithaca, this conclusion should be modified, not only with reference to the cost of the tanks, but also with reference to the annual charge of \$600, to examine and adjust 131 tanks. This cost is quite excessive when the best tanks are used.

In his opening paragraphs the author makes a rather sweeping assertion regarding the present extensive use of automatic flush-tanks for small pipe sewers. In some cities, particularly in those having adopted systems on the recommendation of Colonel George E. Waring, Jr., a very extensive use has been made of such tanks; but in most others their use has been limited to cases where they were more economical than hand-flushing, which fact needs determining in each case.

* Transactions, Vol. x, p. 361.



Volume of Flush given in U.S. Gallons. Velocities given in feet per second.

Horizontal scale gives distances in feet.

Slopes of sewer bottoms given in feet per hundred.

Velocities are calculated (Kutter, $n=0.013$), and are those due to the depths of flow at the respective points, and to the slopes of the sewers.

FIG. 6.

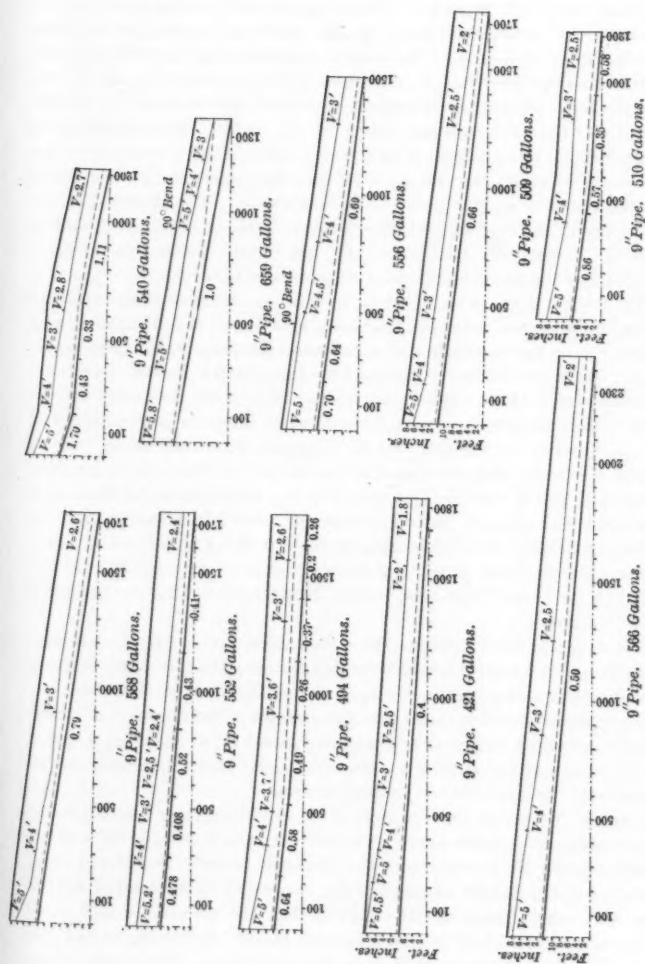
Mr. Hering. The author intimates that the suspending and scouring power of water depends on the velocity and also on the depth of the stream. The depth, of itself, irrespective of the velocity, has nothing to do with this power. Suspension in running water, and, even more so, the scouring power, are almost wholly functions of the velocity. In two streams having different depths, but equal velocities, the suspending and scouring power of the water will also be about the same. In two streams of water having equal depths, but different velocities, the suspending and scouring power will again depend practically on the velocity alone.

The material which is taken out of a sewer, when it is flushed quarterly or semi-annually, is sometimes a growth, a mycelium—the fungus growth in the sewer. It is, perhaps, not offensive, but it obstructs the flow and makes necessary the flushing of the sewer to obtain the full capacity again. At Colorado Springs, Colo., this fungus grows at such a rate that if the sewers were not cleaned out often, they would be completely closed up. The speaker was present when flushing was going on, and was astonished to see the large mass of fungus, amounting to several cubic yards, which came out of the sewer within a few minutes.

Referring to the conclusions at the end of the paper, the speaker is at a loss to understand the “mysterious something which defies definition,” but which is said to produce frequent accumulations in one line of sewers and not in another. Such a mystery has never seemed to arise in the speaker's experience, and if the cases are sufficiently analyzed, he doubts the existence thereof. If, on one hand, the nature of the sewage discharged is observed, and, on the other hand, if the actual velocity measurements are made, as suggested above, any mystery would probably disappear.

Another conclusion states that “a flow of even an inch in a sewer offers a large resistance to the flushing action.” This statement in its implication can certainly not be correct. Sewage is but dirty water, and whether the first inch of flow is sewage or clean water should make no practical difference in the velocity of the flushing water. Certainly the flow of sewage would not offer a large resistance when the flow of clean water offers but a slight resistance. The deposits to be overcome are, of course, supposed to be the same in both cases. Therefore, the speaker cannot agree with the author's proposition that flushing should be done at night. On the contrary, to give the best effect, it should be done when the flow of sewage is greatest, that is, in the forenoon. The flushing water, when added to the sewage, will increase its flow, and, therefore, also its velocity, its scouring and its cleansing effect, to the greatest extent.

The author's diagrams, representing the results of some of his experiments, are very interesting and valuable. They are plotted so that



Volume of Flush given in U.S. Gallons. Velocities given in feet per second.
Dotted line shows depth due to sewage. Horizontal scale gives distances in feet. Full line shows depth due to flush.
Slopes of sewer bottoms given in feet per hundred.

FIG. 7.

Mr. Hering. the axis of abscissas is the time scale, and the ordinates represent the depth of the water.

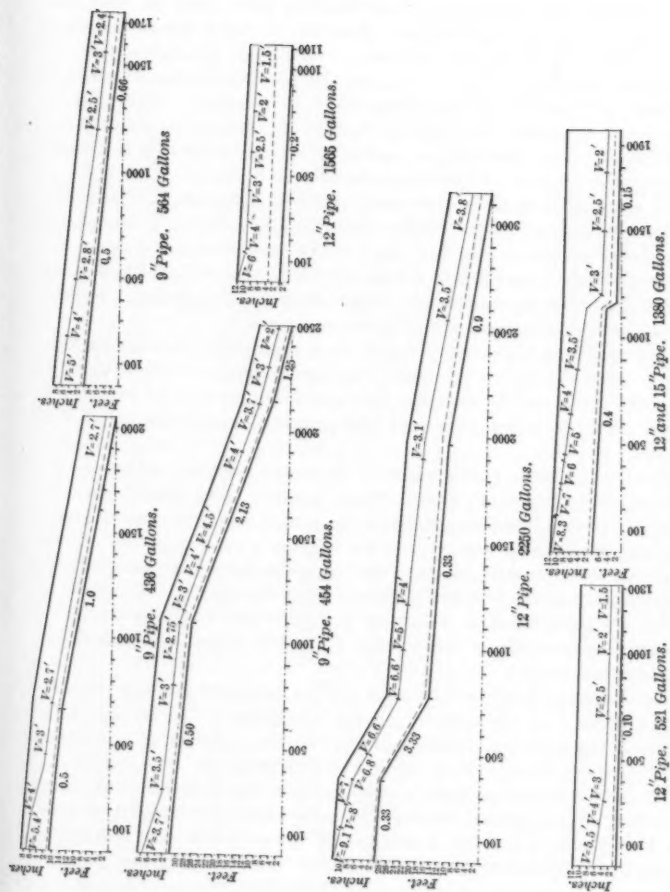
Last year some diagrams were published,* which likewise show the effects of sewer flushing. These are plotted so that the abscissas represent the distance traveled by the flush wave, and the ordinates the velocity of the water. To enable one to further appreciate these results, another plotting is possible, partly combining these two methods and letting the abscissas represent the distance or length of flush and the ordinates the depth of the water. The advantage of this plotting is the possession of a true profile of the sewer and of the flush wave, in which one can see its length and depth at a glance, while the velocities are written down in figures above. The Ithaca data are thus plotted in Fig. 6, and the Adams' data in Figs. 7, 8 and 9. James H. Fuertes, M. Am. Soc. C. E., has kindly assisted the speaker in replotting the above-mentioned diagrams in this manner.

The Ithaca data (Fig. 6), thus re-plotted, show how the velocity gradually decreases with the distance, and show the distances and depths of flow up to which the necessary cleansing velocity is maintained. They also show by figures how long such velocities continue. As stated above, these velocities were not measured, but merely computed. They would, therefore, be somewhat different in practice, but how much is not yet known. As an example, when the flush wave is highest, a velocity of more than 2 ft. per second is maintained for only one minute, and it extends less than 500 ft.; when the water flows at $\frac{2}{3}$ this height, the velocity has continued for over five minutes, and for this length of time it extends only about 400 ft.; and when the water flows at $\frac{1}{3}$ its greatest height, a velocity of over 2 ft. per second has continued for about 7 minutes, but for this length of time has extended only about 300 ft.

This diagram clearly shows the well-known fact, that the greatest benefit from flushing is obtained by maintaining the cleansing velocity as long in time and as far in distance as possible. It is, therefore, desirable to determine for each case approximately the quantity of water needed to obtain a required and definite result in a sewer of a given size or slope, and the author's work materially facilitates this determination for the cases which he has covered.

Mr. Fuertes. JAMES H. FUERTES, M. Am. Soc. C. E.—The author has rendered the profession a valuable service in recording the results of his experimental flushing of sewers, but the speaker regrets that more data, covering a wider range of conditions, were not incorporated in the paper, and would respectfully suggest that the records would have been more complete had he given the elevations of the surface of the water in the flush-tanks as well as in the manholes. The pages of the *Transactions of this Society* are the proper repositories for as many

* By Messrs. Adams & Co., Engineers, of London, England.



Volume of Flush given in U.S. Gallons. Velocities given in feet per second.
 Dotted line shows depth due to surge. Horizontal scale gives distances in feet. Full line shows depth due to flush.
 Slopes of sewer bottoms given in feet per hundred.

FIG. 8.

Mr. Fuertes. such records as can be obtained, and it is to be hoped that in closing this discussion the author will offer as much matter as is practicable.

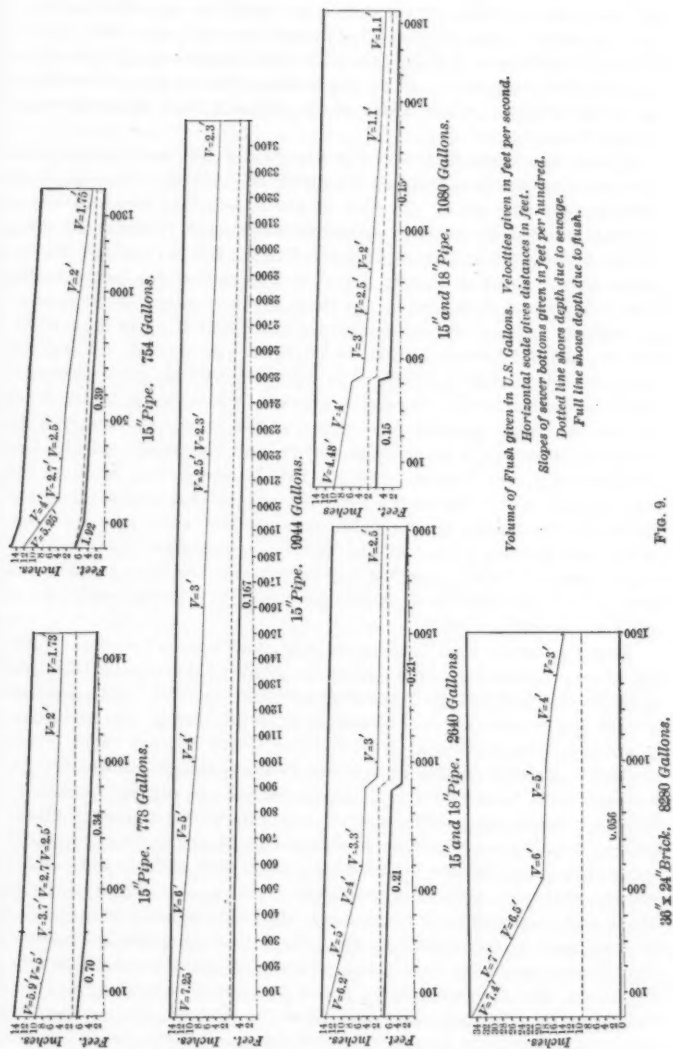
The data presented by the author permit the drawing of some interesting inferences concerning the changes, as to form of wave and velocity of flow, taking place in a quantity of water discharged suddenly, under a head, into a sewer; and permit the correction, by graphical demonstration, of some popular and fallacious notions concerning the action of a flushing wave in a sewer. The idea is commonly expressed, even to-day, that, to be effective as a flush, the water must shoot through the sewer in a solid body like a piston. That this is not true will be demonstrated presently.

In conclusion 10 the author makes the following unqualified statement: "while with a pipe flowing half full, the effect of a flush-tank is scarcely visible." By this very broad assertion he creates the impression that no matter how large the flush-tank, or under how great a head it is discharged, the pipe would not run over half full. Surely this is not the meaning intended to be conveyed.

The speaker's hopes were raised to a high pitch, in reading this paper, when the author proposed the consideration of the hydraulic problems involved in flushing; but a careful perusal of the pages which followed failed to reveal the promised consideration of the subject.

Sewers are flushed with water to clean and wash them out, and to prevent their becoming foul. When deposits have taken place in sewers, due to insufficient grades, poor workmanship or other causes, two operations are necessary in order to remove these deposits. These are, first, to loosen and dislodge the deposits; second, to carry away, in suspension in the water, the matter thus dislodged. The question is: Do the most effective velocities for these two operations exist at the same moment at any given point, or, if not, when does each reach its maximum value?

The scouring power of the wave will be greatest when the velocity at the bottom of the pipe is at the maximum. The transporting power of the wave, on a given grade, will be greatest at a certain point when the mean velocity at that point is greatest. The conditions for maximum scouring power and maximum transporting power are, therefore, not coexistent, because the maximum scouring power is at the toe of the wave as it descends the sewer, while the maximum transporting power occurs at a later time. On the diagram, Fig. 10, is shown the form of the flushing wave discharged into the Green Street sewer, drawn from the author's data. A profile of the wave is shown at the end of the 1st, 2d, 3d, 4th, 6th, 8th and 10th minutes. In this diagram the shapes of the waves are not claimed to be exact as to profile at all points. They are accurate at the points where they cross the



Mr. Fuertes. manholes, and the positions of the toes of the waves were interpolated; the remaining portions of the curves are sketched in. The velocities corresponding to the greatest depths of flow were calculated by the Kutter formula ($n = 0.013$). The velocities marked for the toe of the wave are the components, along the bottom of the sewer, of the velocities of the surface of the water at the given points when the wave reaches those points.

At the first manhole the sewer was nearly full, and probably had been running under a head up to within about 60 ft. of the manhole. After passing this point the foot of the descending body of water, under a free flow by gravity, rushed forward rapidly, the point being 135 ft., 265 ft., 391 ft., 513 ft., 630 ft., 743 ft., 852 ft., and 957 ft., distant from the manhole in 1, 2, 3, 4, 5, 6, 7 and 8 minutes, respectively. Traversing these distances in the times given corresponds to an average velocity between the respective points of 2.25 ft., 2.18 ft., 2.10 ft., 2.03 ft., 1.95 ft., 1.89 ft., 1.81 ft. and 1.75 ft. per second. These are the bottom velocities at the point of the wave, and are the actual maximum velocities at the respective points. When the greatest depth of flow has been reached, the slope of the water surface will be about the same as the slope of the sewer, and the mean velocity less (consequently, the bottom velocity will be much less) than at the point of the wave. Therefore, after the natural flow ensues, the maximum scouring power occurs at the point of the wave, and the maximum transporting power at the moment of greatest mean velocity at any section. This scouring power expends itself in friction and work, and very little head is left for velocity, consequently it has small transporting ability.

At any point the true flushing velocity, with a given volume of flushing water, is, therefore, that due to the grade of the sewer at the time when the depth of flow gives the greatest mean velocity. With deposits loosened up so that they may be entrained in the current, the best flush, in a sewer with a circular cross-section, would be that which would cause the greatest length of sewer to flow about eight-tenths full for a considerable length of time. These remarks apply, of course, to the sewer below the point where it runs full under a head. Under ordinary conditions, 8-in. sewers of moderate slopes will not generally run under a head from a flush-tank for more than 100 ft., and even in extreme cases not much over this limit. Of course, with flush-tanks which will discharge at a greater rate than the capacity of the sewer, on steep grades, the sewer may run with full section for a considerable distance; however, this condition is not frequently met in practice. Therefore, the natural flow in the sewer must be relied on to do the cleansing. In this discussion the term natural flow is used to indicate the flow due to the slope of the sewer only, not to any extraneous head from the flush-tank. A steady flow of water of consid-

erable depth for a considerable time, repeated at certain intervals, Mr. Fuertes would, under most conditions, therefore, be of greater benefit than the frequent discharge of small flushes at the upper end. When a small flush is discharged from a tank the maximum depth of flow at different points will diminish as the wave descends the pipe, and, consequently, the farther away from the tank the less the transporting power of the wave. Particles that were picked up or rolled along by the current at certain points would be deposited again at points further down, and the power of the flush from a tank to remove these deposits will cease beyond a certain distance.

The matter which is most difficult to dislodge from the bottom of sewers is the deposit of street dirt and silt which becomes coated with grease and slime. The discharge from a flush-tank is of great value

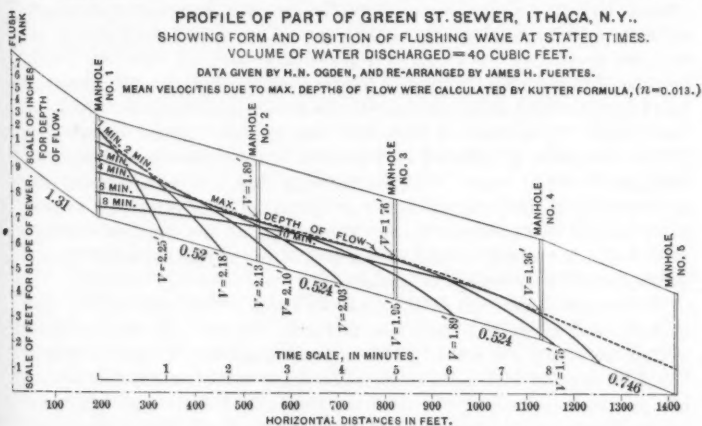


FIG. 10.

in loosening this up so that it may be carried along in the deeper water which follows the toe of the wave.

This graphical illustration of the form of the flushing wave dispels the illusion that to be effective the flush must go down like a piston. That the best results follow the use of a deep flow of water for a considerable length of time, has long been understood and recognized in England and Germany. Numerous cities could be quoted where the provisions for flushing have been designed on this basis. At Munich and Frankfort, for instance, very large underground reservoirs are built at the heads of several sewers, and provisions are made for diverting the water into different branches and creating a deep flow for a considerable time. In this system of operation the idea of a plug of water does not enter in any way; the whole cleansing effect being de-

Mr. Fuertes. pendent upon the flow of water of considerable depth. It is not always possible, however, to obtain topographical conditions favorable to this method of flushing, and then it is necessary to resort to the expedient of intermittent and frequent flushings with comparatively small quantities of water. This may be done either by automatic flush-tanks, a hose or by a water cart. The method to be adopted will be the outgrowth of local conditions.

The speaker is inclined, in most cases, to favor the use of automatic flush-tanks for all dead ends of pipe sewers on all grades. The necessity for flushing exists on steep as well as on flat grades, for the purpose, not only of removing actual obstructions, but for preventing the growths of fungi in the pipes, for preventing the formation of obstructions and for aiding in the ventilation of the sewer. The reasons that he favors the use of tanks are: the potential guarantee against trouble, as stated above, and the cheapness of the method, as compared with other systems that are equally safe.

The author makes out a bad case against automatic flush-tanks, and intimates that those on the Ithaca sewers represent an expenditure equal to about one-half the cost of the system of sewers. In the first place it is stated that the cost of the flush-tanks should be estimated at \$50 each. This is between two and three times the amount they would actually cost; as the manhole at the end of the sewer would be a necessity in any event, and as the amount chargeable to the flush-tank should be the cost of the apparatus and the cost of the labor for placing it in position.

He estimates the cost of the tanks at about 8% of the cost of the system, and adds that their use increases the cost of the separate system by nearly one-tenth. This argument against the use of tanks could be applied with equal force against the use of manholes, which are provided principally in order to locate obstructions should they occur, and the cost of which constitutes about one-fifth of the total cost of an ordinary system of pipe sewers. He estimates the total cost of water at \$3.93 per day, or about \$1 434 per year for flushing the Ithaca sewers. This amounts to about \$0.15 per mile per day. If these sewers were to be flushed entirely with accumulated sewage by means of hand gates, without the use of city water, one man would have to keep clean about 10 miles of sewer per day in order to have the cost of flushing as little as the cost of the water (at Ithaca prices) to be used in the flush-tanks. The cost of the necessary hand gates, special constructions and apparatus would not be much less than the cost of the siphons for the automatic tanks; the repairs would not be much less, and the cleansing received by this method of flushing would not be as satisfactory in pipe sewers as would result from the use of flush-tanks discharging clean water into them.

The author capitalizes the annual expenses chargeable to flush-tanks at about \$10 000 and compares this with the actual cost of pipe laid. The comparison is meaningless, because the costs of water and maintenance are charged to the flush-tanks. These items should be charged against the sewers, as the expenditure is entirely for the purpose of keeping the sewers clean, and the only annual charge against the flush-tanks should be the interest and sinking fund charges on their cost and the actual labor necessary for their maintenance.

As to the necessity of using flush-tanks on 6-in. and 8-in. sewers on steep grades, it is possible, as the author states, that infrequent hand flushing may be quite satisfactory if properly attended to. As in most towns the number of such sewers is generally quite small, the omission of flush-tanks would probably cause a greater expense for maintenance than if they were provided.

With the author's ninth conclusion, that "on grades greater than 3% flush-tanks are unnecessary and their installation is a waste of money," the speaker is not in accord. Cases where such steep grades occur are comparatively rare, and no great mistake will be made by using flush-tanks at their upper ends, and if there is any mistake it will be on the safe side. It must not be lost sight of that these very heavy grades occur nearly always at the upper ends of the long sewers, and that the current of air through them will generally, though not always, be toward the top, at which point disagreeable odors will be noticed if the sewers are not kept clean.

The speaker would suggest, in closing, that with the great hydraulic laboratory recently instituted at Ithaca by the College of Civil Engineering of Cornell University, with which the author is connected, the opportunity exists of producing a great amount of valuable experimental data, and he hopes that the profession may soon feel the benefit of the work that may be done there.

G. W. TILLSON, M. Am. Soc. C. E.—In Omaha the speaker once had an opportunity to see a good deal of the fungus growth alluded to by Mr. Hering. When the Omaha separate system was first constructed, a main sewer was built along the bluffs, and small 6-in. sewers were built at right angles thereto and running up through the business parts of the city. It was intended to have flush-tanks at the heads of these lines, but, because of some trouble over patents, some of the flush-tanks were not efficient. The grades at the lower ends of the sewers were about 6 ins. per 100 ft., while at the upper ends they were from 5 to 8 ft. per 100 ft. A year or so after the sewers had been constructed they became stopped, and upon examination were found to be nearly half full of this fungus growth for some hundreds of feet. Having been built without manholes, it became necessary to dig down and open up the sewers to clean them out, and, as it was found to be impossible to flush them out with water, they had to be cleaned out

Mr. Tillson. mechanically. The sewers gave this trouble as long as they were in use, and finally they had to be enlarged. As the system was extended, and flush-tanks, which flushed every twelve hours, were built at the upper ends of the lines, all such difficulty was avoided, and, with the exception of the first four or five lines that were built, there was no trouble at all from the fungus growth.

While at Omaha an opportunity was afforded to witness the efficiency of a good flush, although it did not come from a flush-tank. The speaker had charge of the construction of an 8-in. sewer, which emptied into a 12-in. sewer. The trench had been back-filled for about 300 ft. and a manhole constructed at the upper end. A storm arose, and, as the trench had not been entirely filled, the manhole was badly washed, and after the storm a large hole was found in it. Whether it had been broken in by some miscreant was never found out, but the manhole was found half full of mud, and it was presumed that the sewer was in about the same condition. Half way down to the outlet, about 150 ft., a T had been constructed in the sewer, and upon digging down at that point the sewer was found to be full of mud. The contractor looked decidedly blue, thinking it would be necessary to take up the entire sewer, clean out and relay it.

The soil in the Missouri valley, or in the Mississippi, as is well known, becomes very slippery as soon as it is wet. Thinking to take advantage of this fact, a fire hose was attached to a hydrant and applied to the T. After the pressure, which at that point was about 90 lbs., had been applied for several minutes, the mud commenced to start, and in a short time it was driven out of the pipe for 150 ft. The hose was then applied to the manhole, and, after some delay, the sewer for the whole length of 300 ft. was cleaned out simply by flushing; the dirt coming out at the lower end in the form of a sausage. Of course, this was only possible because of the nature of the soil, which, as above stated, is very slippery, and when wet is almost like grease.

Mr. Dunham. H. F. DUNHAM, M. Am. Soc. C. E.—In conclusion No. 8, there is a reference to semi-annual or quarterly flushings with hose, which are sometimes sufficient. The speaker would like to know what kind of matter is swept out of a sewer by those flushings, or, particularly, whether it is sediment from the sewage itself or sand that has accumulated? It is important to keep a sewer reasonably clean. If sewage remained, it would become nearly as foul and objectionable in a fraction of one month as it would in any portion of a year. If the flushing is simply to free the sewer from sand and restore its former capacity, the interval would depend upon many external conditions, and could hardly be fixed by a general rule.

CORRESPONDENCE.

WM. B. LANDRETH, M. Am. Soc. C. E.—This paper is of value in Mr. Landreth. that it gives the results of observations of the form and intensity of the flush wave in small sewers and conclusions based on the author's personal experience and correspondence with other engineers.

The writer has had occasion to use flush-tanks on several sewerage systems, both separate and combined, and has closely watched their operation, to determine, if possible, the relations between the grade of the sewers, the amount of water necessary for flushing and the frequency of its application, but he has been unable to arrive at any exact results. The condition of the sewers, whether clean or foul, smooth or rough, has a great bearing upon the amount and rate of flushing necessary. The rate of discharge from the flush-tanks also has some influence upon the results, and, in the writer's opinion, should not be less than from 10 to 15 galls. per second for 8 or 10-in. sewers on grades less than 1 per cent.

The author's conclusion that flush tanks may be profitably used at intervals along a sewer seems correct, especially on flat lines at the foot of steep sewers, as the checking of the sewage flow when it reaches the flat grade causes it to drop the sediment, which has been easily carried on the steep one.

The economic regulation of the flush-tanks on a sewerage system is not easy, and can only be ascertained by experiment, as the quantity of water necessary will vary on different lines.

The conclusions reached by the author seem to the writer to be conservative, and to agree closely with the results of his own observations.

L. J. LE CONTE, M. Am. Soc. C. E.—The necessity of flushing the upper ends of laterals is generally conceded to be a good sanitary measure. The three main principles to keep in mind are efficiency, economy and elasticity. By elasticity is meant easy adaptability to meet all natural changes in the conditions of flow in the sewers of a town, resulting from an increase in population. Experience teaches the writer that the use of fire hose or a direct connection with the water mains of the city fulfills these three conditions to the best advantage, all things considered.

Flush-tanks are expensive and require more or less attention all the time, in order to maintain the flushes at suitable intervals. To avoid vexatious interruptions, the common practice is to increase the supply of water to each tank, thus shortening the intervals between flushes. Where a city is largely supplied with flush-tanks, the willful waste of water due directly to this cause is something almost incredible. The writer knows of one or two extreme cases where towns

Mr. Le Conte. use flush-tanks on a large scale, and nearly half of the entire daily water supply of the town passes through the flush-tanks and into the sewer system. This is always the case where the town or city owns the water supply, or where water is furnished free for all public purposes.